

# Decision & Risk Based Design Structures; Decision Support Needs for Conceptual, Concurrent Design

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**Abstract** - *In this paper, we elaborate on the decision support needs during conceptual, concurrent design. For this purpose, we consider the type of decision aids that might be helpful to the designers during design, and the information needed by the applications of the products of the design that could be captured and structured by these decision aid tools and processes. We explain our current thoughts and recommendations with respect to the research challenges in this area based on our experience with conceptual, concurrent design teams, as well as our synthesis of the first NASA sponsored workshop on “Decision Based Design Structures” that was held on October 6, 7, & 8<sup>th</sup> 2004 to address some of the same issues. The design context under consideration is Space Missions.*

**Keywords:** *Concurrent Design, Decision Support Systems, Risk, and Design Rationale*

## 1 Introduction

Decision making about technology selections for avenues of research across NASA and for formulating an overall program of missions is conducted partially based on the existing body of knowledge and information about future trends and needs. This body of knowledge and information consists of the documentation from the existing mission designs. This documentation often lacks the necessary information – or *design rationale* – to verify the design decisions or clarify the reasons for making the particular design choices or specify the options considered. Furthermore, it is often not apparent how changes to the requirements and assumptions affect the design.

We use the phrase “Decision Based Design Structures (DBDS)” to span the range of issues that arise in providing the appropriate design decision capture, representation, inference, and optimization to support decision making across NASA. This range of issues spans the disciplines of Engineering Design, Design Rationale, and the Decision Sciences. The general thesis underlying this phrase is that it is possible to provide a decision-based structure for the representation of the design. This decision based structure

not only provides decision support during the design process, but also helps with the decision making activities that occur after the design activity is completed

In this section, we provide an overview of our concurrent, conceptual design team, as well as the NASA sponsored workshop on “Decision Based Design Structures”

### 1.1 JPL’s Concurrent, Conceptual Design Team

The Jet Propulsion Laboratory (JPL) employed the concept of concurrent engineering to create the Advanced Projects Design Team (Team X) in April 1995. This team produces conceptual designs of space missions for the purpose of analyzing the feasibility of mission ideas proposed by its customers. The customers often consist of principal investigators representing science communities, who aim to plan new mission proposals. It takes one to two weeks of concurrent design sessions at TeamX to develop a conceptual mission design that addresses the goals of the principal investigators, and the results of this design is documented in a 30 to 80-page report that includes equipment lists, mass and power budgets, system and subsystem descriptions, and a projected mission cost estimate.

Systems	ACS	Instrument	Mission Design
Telecom	Risk	Software	Program-matics
Thermal	Cost	Structures	Configu-ration
C&DH	EDL	Propulsion	Ground Systems
Science	Power	Logistics	Trajectory Visualization

**Table 1: The disciplines in TeamX**

The project design team consists of 20 engineers, each representing a different discipline, and a team leader. Table 1 shows the disciplines. The team leader coordinates and facilitates the mission design process and interacts with the customers to ensure that their objectives are properly captured and represented in the design. Engineers are equipped with techniques and software packages used in their area of expertise and interact with the team leader and other engineers to study the feasibility of the proposal and produce the optimal design for their specific subsystem within their feasible region. Often, there are conflicting or competing objectives for various subsystems and many studies of design tradeoffs are conducted between subsystem experts in real time. Computers used by various team members are networked and there are also large screens for the display of information. Some of the communication between team members, however, happens in a face-to-face manner. Subsystems that need to interact extensively are clustered in close proximity to facilitate the communication process between the experts.

The design process starts with the articulation of the customer requirements and overall concepts by the team leader and the Systems expert. These engineers have met with the customer in a pre-session to discuss the study objective and define the required products. The pre-session is primarily a meeting between the customers, and the team leader and Systems Engineer held a few days before the concurrent design sessions for planning purposes.

The information provided by the customers usually includes the proposal team objectives, the science and technology goals, the mission concept, initial estimates of necessary payload & associated spacecraft and mission design, the task breakdown between providers of parts or functions, top challenges and concerns and approximate mission timeline. This information is often provided electronically in a format accessible to the designers and is partially presented by the customer representatives during the initial session. This information is uploaded into the common directory for the study by the Systems Engineer before the actual design sessions. The design sessions are held on three days of the week – Tuesday, Thursday and Friday, in morning and afternoon sessions. Each session is three hours.

The mission is designed in an iterative manner. In each iteration, the following events take place sometimes sequentially and other times in parallel: The subsystem experts of Science, Instruments, Mission Design and Ground Systems collaboratively define the science data strategy for the mission in question. The Telecom, Ground Systems, and Command and Data Handling (C&DH) experts develop the data return strategy. Then, the Attitude Control Systems (ACS), Power, Propulsion, Thermal, and

Structure experts iterate on the spacecraft design and the Configuration expert prepares the initial concept. The Systems expert interacts with subsystems to ensure that the various subsystem designs fit into the intended system architecture. Each subsystem expert publishes design and cost information and the cost expert estimates the total cost for the mission. Often at this point, the team iterates on the requirements and each subsystem expert refines or modifies design choices. This process continues until an acceptable design is obtained. This design is then documented and submitted to the customer.

## 1.2 Workshop on Decision Based Design Structures

The workshop on Decision Based Design Structures was held on October 6, 7, & 8<sup>th</sup>, 2004. This was an interdisciplinary workshop spanning the areas of:

- Engineering Design
- Design Rationale
- Decision Analysis

The purpose of this workshop was to gauge the need, and plan for the application of processes, technologies and tools from the fields of design rationale and decision analysis to assist in solving the design challenges of NASA's space missions.

On the first day of the workshop, representative NASA Decision Makers at the project, program and enterprise level discussed the current state of practice for decision making across the agency, and the potential utility of Decision Based Design Structures throughout this process.

The second day of the workshop was devoted to presentations by technical leaders in each of the respective fields. The speakers were mainly representatives from academia and spoke about their specific fields of expertise and it's relevance to the problems addressed on the first day. During the afternoons of both days, there were breakout sessions in which key questions were addressed and discussed. Presentations and breakout sessions continued through the last day of the workshop.

## 2. Applications of DBDS

In this section, we briefly describe our perspective on some of the main applications of "Decision Based Design Structures and the potential role of such structures in support of these applications. The information presented here is our synthesis of the relevant sessions and discussions at the workshop.

- Risk Assessment & Failure Prevention.

During design, we conduct risk, cost, and performance tradeoffs. We try to minimize risk by allocating resources to the most critical areas. On the other hand, risky scenarios occur as a result of a combination of events that integrate to cause a failure. Very often some of these events are related to decisions made by the designers, or the management teams, at various levels. Therefore, DBDS can serve as a framework for integrating the significant aspect of the interaction between different individuals involved as it relates to the final design product.

Investigations into the causes of mission failures has time, and time again pointed out the significance of decisions made by management and the need for better communication between the various levels of management, engineers, and operators. The appropriate DBDS potentially solves these problems by providing the appropriate framework for incorporating the important decisions as they relate to the significant events and activities that could impact the space mission in a critical manner. Such infrastructure supports the traceability of action items and consideration of requirements, constraints, and the organizational aspect of decision-making within a logical framework.

- Mishap Investigations

The goal of a mishap investigation is to understand the causes of a mishap in order to prevent recurrences. Mishap investigations often include the accumulation and synthesis of many different types of information, which are in different formats. The sources of information used for conducting mishap investigations include interviews with involved individuals, design specifications, engineering drawings, materials analyses, procedure manuals, risk assessments, hazard analyses, test data, operations logs, inspection logs, defect images, lab reports, training records, site maps, images, debris, meeting minutes, causal models, review item discrepancies, etc. Clearly, gathering this information and reconstructing the decision processes involved is a tedious and time-consuming task. The rationale for decisions made before the mishap are recalled and reconstructed after the fact. Therefore, the benefits of a DBDS are two-fold. On one hand, a DBDS for an existing design helps during the investigation by providing the traceability from the mishap to its potential causes. On the other hand, conducting the investigation using a DBDS will support the investigation by providing traceability into the decisions made during the investigation process and the rationale for taking the specified choices of action. In addition, such a framework can support decision making during this process for optimization considerations.

- Design Reuse & Re-design

If we seek to make even small changes to an existing mission design, or in retrospect seek the motivation for one

or more design decisions that were made in the design process, it won't be possible to use the existing documentation to investigate these issues after the process is completed. Therefore, it is not possible to investigate the sensitivity of the design to changes in the design parameters, or trace back the many decisions to their causes afterwards. In fact, it may be necessary to conduct a whole new team study to investigate a mission with slightly different requirements. Clearly, providing the means to trace back decisions, conduct sensitivity analyses and capture the effects of small changes can help utilize resources more efficiently. In order to re-use an existing design or use an existing design for further exploration of the trade space, it's important to have a clear articulation of the assumptions, constraints, requirements, performance parameters and traceability into the trades and decisions considered.

- Decision Support

We define decision support activities to include all techniques using analyses & syntheses of design information to give insight to the designers to better focus their efforts and make better-informed decisions. These techniques include analytical, simulation based and empirical models that represent the physical behavior of the system and/or subsystems and the uncertainties associated with them. They also include data mining, machine learning, and reasoning techniques that analyze the data generated during the design process to give further insight to the designers. Considering the utilization of Decision Theoretical approaches for finding optimal decisions can also provide decision support. The utility of a DBDS in lieu of the techniques mentioned above is to provide a framework for the appropriate combination of these techniques to meet the objectives in question.

- Technology Road Mapping & Program Planning

Program Offices across NASA typically make decisions about allocating funding for the research & development of new technologies and future programs. These decisions are made based on the existing body of knowledge and information about future trends and needs. The body of knowledge and information includes the existing documentation from the missions designed. These are widely disparate sets of missions, and the commonalities between them are not readily apparent. Information about which technology options were dominant and which possibly better paths were rejected due to the lack of appropriate enabling technologies in the area is often unavailable. The existence and type of relationship between these potential technologies is also unclear. The proposed DBDS provides a framework for the capture, representation and execution of the information required for making such assessments.

### 3. Decision Support Needs

In this section, we describe the decision aid tools and processes that we believe might aid the designers in our concurrent engineering team during design, on one hand, and the contribution these decision aids can make to the design products in meeting the needs of their applications, on the other hand.

The process of concurrent design within the TeamX environment is very intense [2-5], and designers typically multi-task by designing their own specialized subsystem at the same time as they get the relevant mission information from the team Leader and Systems Engineer, and relevant information from other subsystem designers. Information regarding other subsystem designs, as well as the changing requirements and assumptions as the designers design choices and decisions during the mission design also needs to be taken into consideration. The means for communicating this information is either through the underlying data base (ICEMAKER), through which designers can send and receive values for their design parameters, the “Systems” spreadsheets that encompass the high-level system requirements and are maintained by the System Engineer, or by face-to-face communication with other designers [2]. The dependencies between the various subsystems and the design rationale of the individual designers are not explicitly captured or represented by the underlying System models. This lack of explicit capture and representation seems to us to create confusion amongst the designers at times, and results in the unnecessary use of time and energy.

In our view, the consideration of the design process as a series of inter-dependent decisions and the articulation of the dependencies between the decisions made by various subsystem designers during the decision making process could eliminate this confusion and support the decision making of the experts during design. It should be pointed out that to the best knowledge of the authors, the scope of this hypothetical decision support tool/process is broader, and more application specific than most available decision aid tools. This is because on one hand, it covers the whole spectrum of space mission design as it encompasses the dependencies between all the different subsystems involved in a space mission, and on the other hand, it requires specific knowledge about the underlying system model of a spacecraft in order to provide the most value. To the best of our knowledge, decision support tools typically require the decision maker to input all the relevant information before each analysis. This is impractical during the rapid process of space mission design at the TeamX level. In order for the tool to be applicable during the design process in our concurrent engineering design team, it needs to be pre-seeded with information about the system structure. In addition, it would be useful if the additional information generated during the design sessions is automatically

captured, and mined for relevant knowledge to be incorporated into the decision problem. This requires the combination of Decision support tools and processes with techniques and technologies for Systems Modeling, Design Rationale Capture and Representation, Data-mining, and Knowledge Management.

The advantage of using the process described above for the products of the design process is two-fold. On one hand, better informed decision making during the design process leads to better decisions and a more reasonable, and well thought out design. On the other hand, the capture and representation of the design information in the context of a decision problem allows for the traceability of the decisions and the understanding of the rationale underlying the design choices. This in turn provides value for each of the various applications described in section 2.

### 4. Challenges & Research Areas

In order to meet the goals outlined in section 3, we identify the following areas in need of further research & development:

- Tools & techniques for integration and representation of heterogeneous models/ideas/information.

Most of the information available both during and after the design process is in different formats, and at different levels of fidelity. Techniques for the appropriate integration and combination of these multiple formats, and levels of fidelity would greatly help in utilizing all available information for making better informed decisions all along.

Appropriate representation of this information would facilitate the communication between various stakeholders and designers, hence resulting in better-informed decision making for all.

- Integration of Design Rationale & Decision Support techniques

The capture of the rationale for making design decisions should go hand in hand with the use of Decision Support techniques for decision management and optimization.

These techniques include uncertainty & risk management approaches. These two classes of approaches have traditionally been studied by different groups of researchers, yet their combination provides value beyond the combined value of each of them independently.

- Integration of Data Capture & Data mining techniques

The capture of design information is useful only if it is appropriately mined for the useful information. Therefore it is important to integrate techniques for data capture with data mining techniques to provide this utility.

- Consideration of the Social System Model in the Design Process

The social system model often plays a very big role in the generation of the final design product. On one hand, expert opinions contribute to the design decisions, and on the other hand, much of the cross cutting information is communicated verbally between the experts. It is therefore important to consider this social system explicitly during the process of designing the process of conducting a design process.

#### **4.1 Effective Implementation & Operation of Decision Based Design Structures**

The key challenges to the effective implementation & operation of Decision Based Design Structures are identified as below:

- Defining standard means of communication between various stakeholders.

The stakeholders are the designers, the customers of the design and the researchers in the representative fields. Often there is a disconnect between these stakeholders and each have a different understanding of their needs and wants. Defining standard, well established means of communication facilitates this process.

- Techniques for integrating disparate models, teams, tools and data types.

Existing models are at different levels of fidelity. Teams have various cultures and are located in different organizations. The tools used by these teams are disparate. The relationships between these tools, overlaps, feasibility and usability of each of them are unclear. Data available in the teams is also disparate and of various levels of fidelity. Tools and techniques for integrating all these disparate entities would provide great value.

- Development of techniques that are “invisible” to the process.

Existing techniques are not “invisible”. The time & effort taken for using these tools doesn’t necessarily justify their value.

## **5. Summary & Conclusions**

A brief description of the Concurrent, Conceptual design team at the Jet Propulsion Laboratory (TeamX) and an overview of the first NASA sponsored workshop on “Decision Based Design Structures” was provided in this paper. This led to our discussion about our thoughts and observations about the Decision Support needs of TeamX and their utility to the designers, as well as the design product. We concluded by high-lighting the major challenges and areas for research and development.

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